Time Synchronization of Spatial Separated Areas for AV-Production

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***Abstract*—For Audio and Video (AV) Production, time synchronization between different devices is an important part to achieve a high-quality AV production. A well-established method for synchronizing devices is the use of clock signals like wordclock, which might not be a convenient solution when the spatial distance between devices increases. This work is aiming to introduce to the possibility to use an IP-based standard to perform the time synchronization between different devices: IEEE 1588 Precision-Time-Protocol (PTP). Therefore the protocol is evaluated according to his performance under different network conditions using a network emulator and a test-scenario through a Wide-Area-Network. The performance of the time synchronization using PTP shows promising results.**

***Keywords*—IEEE1588, time synchronization, PTP, precision-time-protocol, WAN, wide-area**

I. Introduction

Time synchronization in Audio and Video (AV) production is one of the key issues to provide high quality results. This means, if a variety of AV signals is transmitted or recorded simultaneously, the signals need to be aligned properly, especially to avoid time hops when switching between the recording or transmission devices.

When spatial distances between devices increase, the establishment of a suitable synchronization gets even more challenging. This might be the case with immersively connected rooms, where e.g. a live concert takes place at one location, and the ambience of the event should be emulated for listeners in a far distant listening environment.

A well-established synchronization technique in AV productions is the use of a digital clock signal like wordclock, that can either be derived from the incoming data stream or separately transmitted via an additionally wired connection between the devices and a master clock. However, in setups with large spatial distances this method might not be the most convenient option. Here the use of the existing IP-networks like the internet and other available IP Wide-Area-Networks (WAN) can be a suitable option.

When synchronizing two devices, that are connected via a WAN, different options are possible. For wireless connections, a global timing service is offered e.g., by the Global Positioning Service (GPS) [1] or, for the European Continent, by the long wave transmitter DCF77 [2]. The use of either one of these services requires a receiver for wireless signals.

If a wireless synchronization is considered, the necessity of a high-quality reception of the timing signal needs to be taken into account. Production studios are commonly located indoors, which can be a major disadvantage if using GPS or DCF77. If the location of interest only allows week or even no signal transmission, a wireless synchronization cannot be achieved.

In these situations an alternative approach might be suitable: the use of an IP-based synchronization protocol like IEEE1588 Precision-Time-Protocol (PTP) [3]. Already used in the Programm Making Special Events (PMSE) industry for local areas [4, 5], this standard also offers the possibility to be utilized in WANs. In [6, 7] R. Zarick et. al. proposed a method to synchronize devices using PTP through a network with different switches (mostly PTP-aware) and a non-PTP-aware network emulator. In their work, they were able to demonstrate the influence of different network parameters like latency and cross-traffic on the synchronization accuracy of PTP, in small and local networks.

In this work, the focus is on expanding the existing approaches by testing the behaviour and performance of PTP under different and high-jitter network conditions like stated in a large network with multiple switches and hops (WAN) and the usage in a real-world WAN, established between two cities in Germany.

In section II, the transmission channel model of IP-networks and the PTP is reviewed. In section III, the used software and the measurement setups are described. In section IV, the results of the measurements are shown and in section V the paper is concluded.

II. Background

A. Transmission channel model

A simple WAN can be demonstrated like a connection between two spatial separated devices that are connected over Ethernet like copper and/or fiber. Regarding that the WAN connection is deployed by a local internet provider, the transmission path through the network is unknown to the user. This means, that the routing through the network, the number of switches or routers (also called hops) and, thereby, the specific parameters of the network connection are unknown. In Fig. 1 there is an example for a connection between Side A and B shown. The unknown network in-between introduces

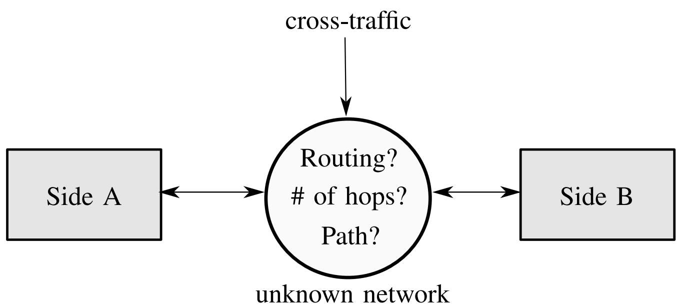

Fig. 1. WAN connection over a unknown network

different parameters, which influences the transmission. These parameters (routing, number of hops, cross-traffic) lead to different network properties, like latency, jitter and packet-loss. In terms of time synchronization, the important parameters can be divided into three types:

- Static: This includes transmission parameters that do not change over time, like transmission asymmetry and average transmission latency.
- Dynamic: This includes transmission parameters that changes frequently over time, like latency jitter and packet-loss.
- Pseudo-static: This parameters are usually static the most of the time, but changes from time to time. For example a change in asymmetry by changing the routing of the traffic through the network.

To enable a time synchronization between the two sides, these described influences or errors have to be overcome by the synchronization method.

B. IEEE1588 Precision-Time-Protocol

A widely-used method to handle the influences of the transmission channel (chapter II-A) for time synchronization is PTP. While the Network Time Protocol (NTP) lacks in accuracy and precision and White Rabbit need the use of specific hardware, PTP can be used on most devices, that are connected to the network. [3, 8, 9].

For achieving a time synchronization using PTP, the transmission delay of the network and the time offset of the client need to be determined. Therefore, several messages are sent through the network to generate Time-Stamps (TS) (t_1, t_2, t_3, t_4), either at transmitting or receiving (see Fig. 2).

- $SYNC$: By sending this message the timestamps t_1 at the master node and t_2 at the client are generated.
- $FOLLOW\_UP$: This message transmits the timestamp t_1 to the client node.
- $DELAY\_REQ$: The delay request message is sent by the client to the master node to generate the TS t_3 and t_4, which are used to calculated the transmission delay.
- $DELAY\_RESP$: The delay response message is used to transmit the TS t_4 taken at the master to the client.

The time interval for sending the messages $SYNC$ and $DELAY\_REQ$ can be individually configured and vary e.g., from 0.125 second to one second (see [10]) .

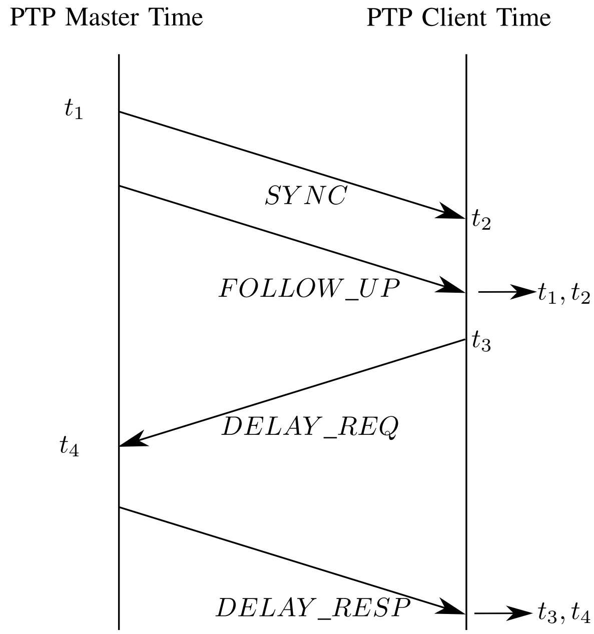

Fig. 2. Transmitted packets and corresponding timestamps in IEEE1588 Precision Time Protocol

The mechanism of time synchronization used by e.g., the Linux implementation of PTP "linuxptp" [11] is defined by several processing blocks: path delay estimation, delay filtering, time offset estimation, servo controlling block (see Fig. 3):

- Path delay: The path delay d is calculated using all four TS (1). Therefore the assumption ,that the path delay between master and client is symmetrical, is needed. Investigations for an asymmetric transmission are done in [12].

$$d = \frac{(t_2 - t_1) + (t_4 - t_3)}{2} \tag{1}$$

- Delay Filter: Filtering the calculated path delays d over several measurement steps M is mandatory to lower the delay jitter introduced by the network. In linuxptp, there are two different filters implemented: Moving Average and Moving Median with different filter length M.
- Time Offset: The resulting time offset of the client to the master node is defined by (2) using the timestamps t_1, t_2 and the filtered path delay $\tilde{d}$.

$$\Delta T = (t_2 - t_1) - \tilde{d} \tag{2}$$

- Servo Controller: By using TS t_1 and t_2 in (2), the calculated ΔT is also affected by the delay jitter of the network transmission. Therefore, a servo controller is used to smooth the jitter, e.g., PI-controller or linear regression are implemented in linuxptp.
- Clock Adjustment: The clock of the client is adjusted by the calculated offset given by the servo controller. This is done by either stepping the clock for a large calculated offset or by adjusting the clock frequency for smaller offsets.

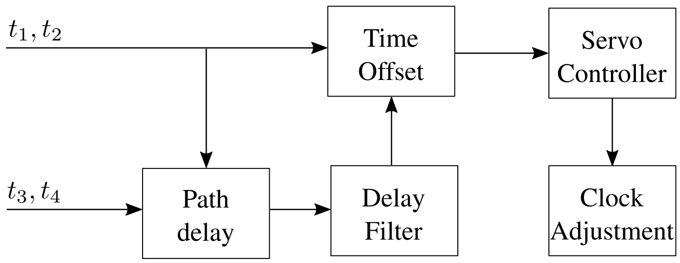

Fig. 3. Processing of the PTP TS to adjust the clients clock

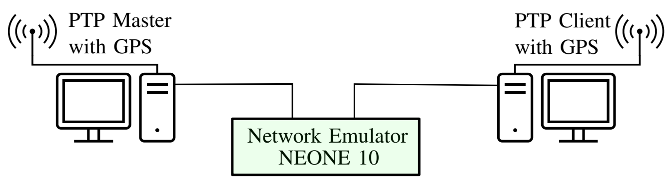

Fig. 4. Laboratory setup with network emulator

By repeating all these packet transmission and calculation steps, the clients clock can be adjusted to the master clock. PTP is able to handle and weaken the static and dynamic effects of the transmission by using the described methods. The pseudo-static effects are more difficult to overcome. The algorithm needs to adjust to the changes and therefore, the algorithm can be evaluated by the reaction time in handling these effects.

III. Measurement Setups

To evaluate the performance of PTP in WAN, two different setups were build. The first setup is a laboratory setup using a network emulator to emulate different networks and simulate the behaviour of PTP under different network conditions. The second setup is a real network connection established between the German cities Munich and Hanover.

A. Software

For both setups described in this chapter, two PCs equipped with an Intel i5 processor and an Exanic PTP GM from Exablaze [13] are used. The Exanic PTP GMs serve as GPS time reference at each PCs. As operating system Ubuntu 16.04 and as PTP software the open stack "linuxptp" [11] are used. While the PTP master synchronizes its system clock to the GPS time of the Exanic PTP GM using the program "phc2sys", the PTP client compares its system time, which is synchronized using PTP, to the GPS time using the program "phc_ctl". Therefore, a measurement of the offset between the system clock and the GPS time at the client node is produced every second. All these used software are open source for ubuntu.

Further, the clock synchronization procedure described in II-B is performed once per second.

B. Emulated Network

The laboratory setup for simulating different network scenarios is shown in Fig. 4. As network emulator the model

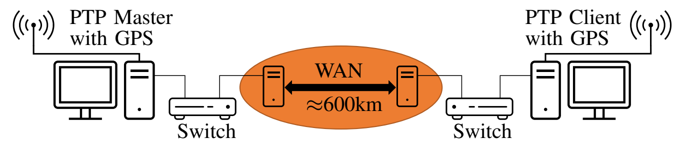

Fig. 5. Wide-Area-Network setup between Munich and Hanover

"NEONE 10" from Itrinegy is used [14]. The PTP master and the PTP client are each connected to the network emulator via copper Ethernet (1Gb/s). To enable an evaluation of the achieved time synchronization, both PTP devices are connected to a GPS reference time source via Exanic PTP GM. The PTP master synchronizing its clock to the GPS time, while the PTP Client compared its achieved synchronized time to the GPS time.

C. Wide Area Network

For the measurement setup for testing PTP through a WAN, the network emulator is exchanged by a high quality network with available data rate of 1 Gbit/s provided by a network operator in Germany. The WAN is established between the German cities Hanover and Munich, with distance of around 600km. The additional switches shown in Fig. 5 are needed for distributing other traffic also routed through the network within this project [15]. For the synchronization measurement these switches can be regarded as part of the WAN.

IV. Results

A. general

To evaluate and to compare different configurations of the synchronization protocol PTP, the value for the standard deviation is used. At every synchronization step, the offset of the clients clock to the GPS time is measured. After a specific time, an average or mean value μ (3) and a corresponding standard deviation σ (4) of these offset measurements ΔT_n are computed.

$$\mu = \frac{1}{N} \sum_{n=1}^{N} \Delta T_n, \tag{3}$$

$$\sigma = \sqrt{\frac{1}{N} \sum_{n=1}^{N} \|\Delta T_n - \mu\|^2}, \tag{4}$$

with N as the number of observed offset samples.

The standard deviation can also be compared to the latency jitter of the network like introduced by network emulator. The latency jitter of the emulated network is a Gaussian distribution with constant mean and a specific standard deviation. Also the latency measurements through a WAN can be regarded as almost Gaussian shaped (Fig. 6).

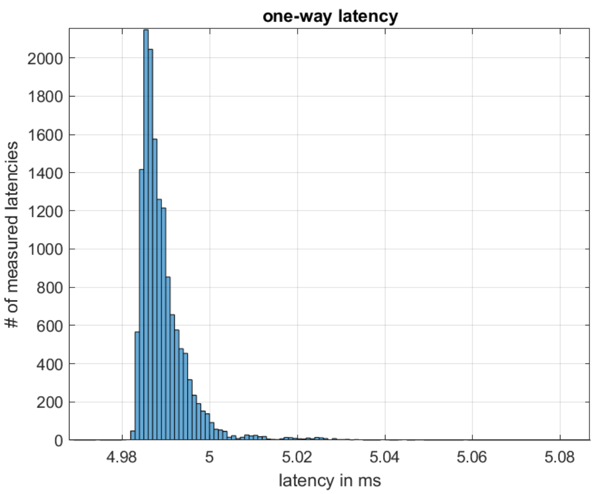

Fig. 6. Example for the distribution of transmission latencies through WAN

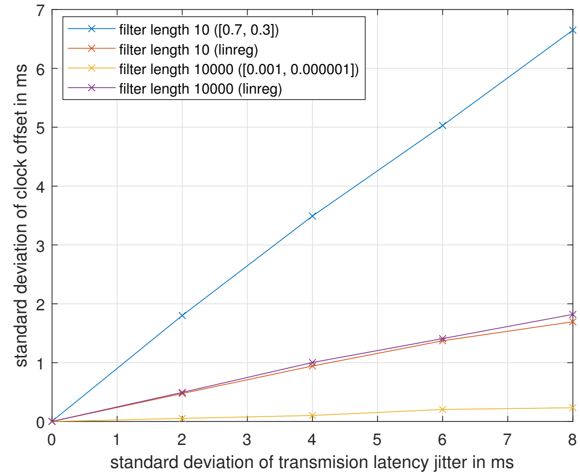

Fig. 7. Comparison of different PTP configurations in case of filter length (moving median) and servo controller ([P, I] or LinReg.) for different emulated network latency jitters

B. Emulated Network

By using the setup shown in Fig. 4 the capabilities of the synchronization algorithm PTP are evaluated. Therefore different configurations are used and tested according to their accuracy. As delay filter, the moving median filter is used to compensate for jitter peak values. IT is clearly stated, that in environments with high jitter peak values a moving median filter achieves better performance a moving average filter. Therefore, the considered parameters in the PTP configuration are length of the moving median filter and the servo controller (PI controller or Linear regression).

In Fig. 7 the achieved synchronization accuracies for different configuration are shown. The evaluation is done for different standard deviations of the network latency jitter introduced by the network emulator. The best result in terms of the synchronization accuracy is obtained by a large filter length of 10000 samples and low proportional and integral values (P= 0.001, I=0.000001) for the PI controller. By using the linear regression algorithm as servo controller, the length of the delay filter is of minor influence. The filter lengths of 10 and 10000 do result in similar results for synchronisation accuracy.

C. Wide Area Network

A main disadvantage of using high values for the delay filter and low values for the PI controller is the slow reaction time to pseudo-static effects. If the average transmission delay of the network connection is changing by e.g. re-routing or higher data throughput (cross-traffic), PTP needs more time to adjust to the new circumstance when a large delay filter is used compared to a short filter length. An example is shown in Fig. 8, where cross-traffic is applied at the timestamp at 4 000s up to 33 000s. The cross-traffic leads to a pseudo-static effect in the transmission and the algorithm has to re-adjust its calculations, which causes the demonstrated peaks in the measurement of the clients offset.

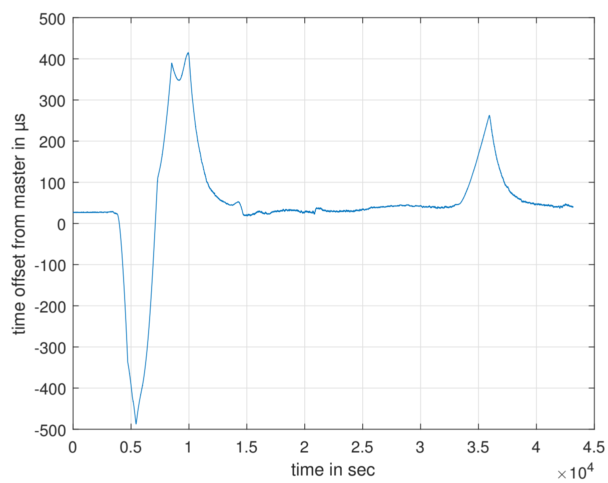

Fig. 8. Offset of PTP client clock over time through WAN using moving median delay filter (length 10000) and PI controller (P=0.001, I=0.0000001)

By using the linear regression algorithm with delay filter length of 10 (moving median), the reaction and re-adjustment after change of the average transmission delay shows a shorter reaction time, see Fig. 9.

In Fig. 10 and 11 examples for the synchronization accuracy in terms of the distribution of the offset measurements using PI controller and linear regression is shown. Therefore, the time offset of the PTP client to GPS time are measured over about 9 hours, while cross-traffic of about 520Mbit/s is applied by transmitting audio and video data streams used for demonstrating immersively connected rooms for AV production. The influence of cross-traffic on the synchronization accuracy of PTP is further investigated by [6].

For both measurements, the synchronized clock shows an offset to the GPS time. The averaged offset for the PI controller

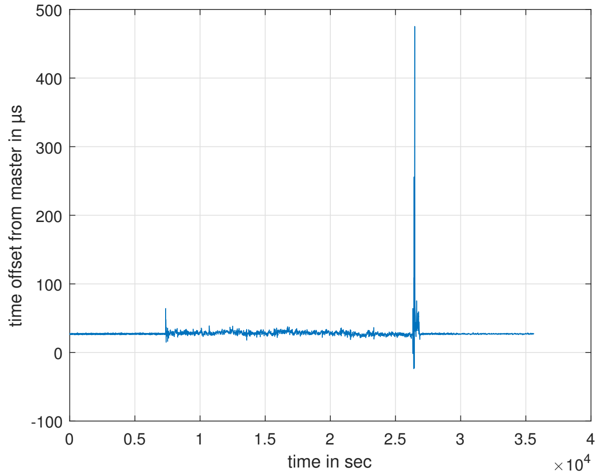

Fig. 9. Offset of PTP client clock over time through WAN using moving median delay filter (length 10) and Linear regression algorithm

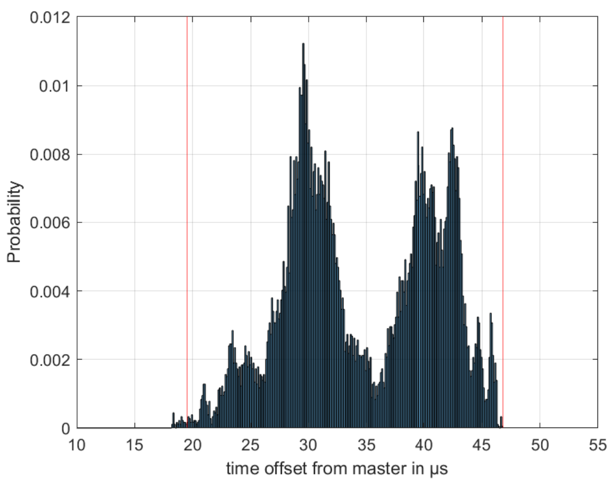

Fig. 10. Offset measurement distribution for PTP synchronization through WAN using moving median delay filter (length 10000) and PI controller (P=0.001, I=0.0000001)

is about $35\mu s$ and for the linear regression about $28\mu s$. This can be explained by a small transmission asymmetry introduced by the WAN. For the synchronization accuracy, the 99.7-percentile of these measurements are demonstrated with red lines; which means, that 99.7% of all measured values are in between these red lines. The 99.7-percentile of the linear regression is $\pm 8\mu s$ compared to $\pm 13.5\mu s$ for the PI controller.

In summary, the use of the linear regression algorithm shows slightly better results compared to the PI controller. In terms of the time of reaction to changes in the network, the linear regression should also be preferred. For both configurations, PTP achieves a synchronization accuracy below 1ms, which is the requirement for AV production.

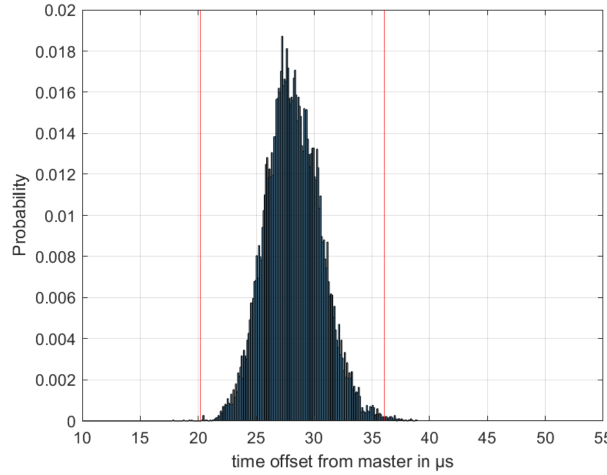

Fig. 11. Offset measurement distribution for PTP synchronization through WAN using moving median delay filter (length 10) and Linear regression algorithm

V. Summary

In this work, the capabilities of IEEE1588 Precision-Time-Protocol (PTP) through a Wide-Area-Network (WAN) are evaluated. This is done with the aim to provide a time synchronization through WANs for Audio and Video production on spatial separated areas. For the measurements, two different setups are built: the first, using a network emulator to emulated the behaviour of latency and jitter in different WANs and the second, using a connection through a WAN between two cities in Germany (distance around 600km) to compare the emulated results.

While using the network emulator, it is demonstrated that PTP can significantly reduce the synchronized clock jitter compared to the introduced transmission latency jitter. By evaluating different configuration, the linear regression as servo controller is achieving the best results in terms of accuracy and reaction time to changes in the WAN.

Further, PTP is used through the WAN provided by the second setup. In this case, the synchronization accuracy provided by PTP is far below 1ms, which is the requirement provided by the PMSE industry for Audio and Video production.

For evaluating the performance of PTP in WANs with higher latencies and jitter (e.g. connection between countries or through the transatlantic cable), further studies and tests have to be made.

Acknowledgment

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REFERENCES

[1] W. Lewandowski and C. Thomas, "Gps time transfer," *Proceedings of the IEEE*, vol. 79, no. 7, pp. 991–1000, 1991.

[2] D. Piester, P. Hetzel, and A. Bauch, "Zeit- und Normalfrequenzverbreitung mit DCF77," 2004.

[3] IEEE, *IEEE standard for a precision clock synchronization protocol for networked measurement and control systems*. New York, N.Y: Institute of Electrical and Electonics Engineers, 2008.

[4] Don Pannell, "Audio video bridging(avb) assumptions: Version 14," 2008.

[5] M. D. Johas Teener and G. M. Garner, "Overview and timing performance of ieee 802.1as," in *IEEE International Symposium on Precision Clock Synchronization for Measurement, Control and Communication, 2008*. Piscataway, NJ: IEEE, 2008, pp. 49–53.

[6] R. Zarick, M. Hagen, and R. Bartoš, "The impact of network latency on the synchronization of real-world ieee 1588-2008 devices," in *2010 IEEE International Symposium on Precision Clock Synchronization for Measurement, Control and Communication*, 2010, pp. 135–140.

[7] R. Zarick, M. Hagen, and R. Bartoš, "Transparent clocks vs. enterprise ethernet switches," in *2010 IEEE International Symposium on Precision Clock Synchronization for Measurement, Control and Communication*, 2010, pp. 62–68.

[8] D. Mills, U. Delaware, J. Burbank, and W. Kasch, "Network time protocol version 4: Protocol and algorithms specification," 2010.

[9] G. Daniluk and T. Wlostowski, "White rabbit: Subnanosecond synchronization for embeded systems," 2011.

[10] SMPTE, *ST 2059-2:2015 : SMPTE Profile for Use of IEEE-1588 Precision Time Protocol in Professional Broadcast Applications*. The Society of Motion Picture and Television Engineers, 2015.

[11] "The Linux PTP Project," Accessed: 2021 07 26. [Online]. Available: http://linuxptp.sourceforge.net/

[12] M. Levesque and D. Tipper, "Improving the ptp synchronization accuracy under asymmetric delay conditions," in *2015 IEEE International Symposium on Precision Clock Synchronization for Measurement, Control, and Communication (ISPCS)*. IEEE, 11.10.2015 - 16.10.2015, pp. 88–93.

[13] Exablaze, "Exablaze ExaNIC GM," Accessed: 2020 11 17. [Online]. Available: https://exablaze.com/exanic-gm

[14] Itrinegy, "NE-ONE Professional Model 10," Accessed: 2021 07 26. [Online]. Available: https://itrinegy.com/ne-one-professional-range/

[15] "Project LIPS - Live Interactive PMSE Services," Accessed: 2021 08 02. [Online]. Available: http://lips-project.de/